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Technical Report

ANALYSIS OF PREVENTIVE MAINTENANCE POLICIES FOR NAVY TRANSPORTATION EQUIPMENT

June 1971

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13. ABSTRACT

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1. Scheduled preventive maintenance service,
2. Limited preventive maintenance service,
3. Breakdown maintenance service, and
4. Manufacturer's prescribed preventive maintenance.

A digital computer program was used to expedite the analysis and provide cost and performance data. For the 12 vehicle classes analyzed to determine effectiveness of the four maintenance policies, the results indicate the manufacturer's prescribed preventive maintenance policy was the most cost-effective approach.

Changing from the scheduled preventive maintenance policy now used to the manufacturer's prescribed preventive maintenance on the 50,820 vehicles currently in use by the Navy (in categories 91 through 96) would result in a cost savings of $5.9 million per year.

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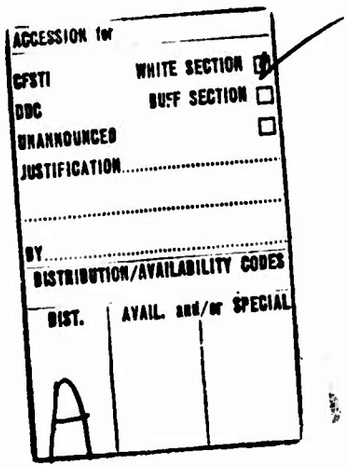

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INTRODUCTION

This study comparing the effectiveness of four vehicle maintenance policies was begun in July 1966. The collection of data and analysis of results were continued for 4 years, during which time the following engineering personnel at NCEL were responsible for the coordination of the program:

1966-1967	W. L. Richardson
1968-1969	B. C. Witherspoon
1969-1970	R. E. Bergman

The final phase of this project, which included drafting of this report, was coordinated by A. Jokubaitis.

The analysis described in this report was begun in 1966 for the Naval Facilities Engineering Command (NAVFAC)—then the Bureau of Yards and Docks. The goal of this study was to determine the optimum equipment maintenance policy, based on a determination of total operating cost, reliability, and operational readiness of Naval construction equipment. For a number of years, the current system of preventive maintenance has been the common and accepted practice used by some elements of industry and the military in the maintenance of mechanical equipment. In general, preventive maintenance consists of (1) periodic scheduled inspections of certain mechanical components likely to fail or wear out and (2) the performance of necessary service or repair operations where inspection indicates the requirement. It is recognized that preventive maintenance reduces vehicle downtime and increases, to some degree, equipment reliability.

Because preventive maintenance also tends to invite a degree of overmaintenance unless it is rigidly controlled, consideration was given to using a policy of controlled breakdown maintenance, where equipment failure is less critical. Breakdown maintenance policy consists of a completely "hands off" policy; repairs are not conducted until the vehicle is inoperable or unsafe for operation. A question requiring conclusive resolution which has been considered in this study is whether the reduced maintenance costs resulting from such a system would be offset by higher capital costs due to increased downtime or high operating cost due to the disruptive effect.

To answer the above question, the Naval Civil Engineering Laboratory (NCEL), under NAVFAC sponsorship, established a test program to examine the relative merits of preventive and breakdown maintenance policies and to determine which policy is the most cost effective. Preventive maintenance was further subdivided to allow for a finer distinction of policy, and the following four policies were evaluated to determine the optimum approach:

Policy 1—Scheduled Preventive Maintenance Service

This concept (currently in effect) incorporates a system of periodic scheduled inspections of certain mechanical components and accessories that are likely to fail, wear out, or require adjustments. Service or repair operations are performed when inspection indicates the need.*

Policy 2—Limited Preventive Maintenance Service

This concept is limited to chassis lubrication (except units equipped with seal systems which are governed by the manufacturer's prescribed service intervals) and oil and filter changes at 2,000 and 4,000 miles, respectively. It includes no mechanical inspection—mechanical inspections, repairs, or adjustments are made only when parts fail or when the driver or operator reports a malfunction.

Policy 3—Breakdown Maintenance Service

This no-maintenance approach is a "hands off' policy. Under this concept the mere fact that a driver or operator reports a malfunction or deficiency does not in itself justify repair unless it is determined by the inspector that the complaint is valid and safe operation of the vehicle is in jeopardy.

Policy 4—Manufacturer's Prescribed Preventive Maintenance Service

This concept is governed by the manufacturer's prescribed service.

Tests were begun at CBC, Port Hueneme, California, during November 1966. Vehicles were divided into 12 classes and were further subdivided into the four maintenance policy groups for comparison. Data were collected

* Department of the Navy, Bureau of Yards and Docks. NAVDOCKS P-300: Management of transportation equipment. Washington, D. C., June 1964.

between November 1966 and May 1970, resulting in 12,000 units of maintenance data which were processed through a specially designed computer program called VEHMT.* The results from this comparison are the subject of this report.

DATA REQUIREMENTS

All data, regardless of the type of vehicle concerned, were initially recorded on the shop repair order, NAVFAC 1120-TF-1. This form provided a means of identifying:

the vehicle and the maintenance policy to which it is assigned

date and time in and out of the shop

labor time

delay time

vehicle mileage at entry into shop

types of repair accomplished

labor cost (by repair classification)

parts used and their cost

shop release time, if any

inspector and supervisor

Identification Codes

The types of repair and the labor charges were classified by the following numbering system:

Code	Component	Code	Component
6	lube	16	clutch
9	accessories	17	drive train
10	engine	18	brakes
11	ignition system	19	steering
12	electrical system	20	wheels and tires
13	fuel system	21	hydraulic
14	cooling system	22	battery
15	exhaust system		

* The program listing for program VEHMT, which is in FORTRAN IV for the IBM 7094 computer, is available from NCEL. Inquiries should be addressed to Commanding Officer, Naval Civil Engineering Laboratory, Port Hueneme, California 93043, Attention: Code L64.

All events (that is, cases in which a vehicle comes into the repair shop and a repair order is prepared) were classified according to the work required as follows:

scheduled maintenance

repair of interim failure*

repair of vehicles necessitated by accident

Equipment Classes

The maintenance study described in this report covers 376 equipment units. They were divided into 12 vehicle or equipment classes to provide for more meaningful data comparison. The 376 items were also subdivided, within each equipment class, into separate maintenance policies, as shown in Table 1.

Table 1. Equipment Classes

Equipment Class	Description	No. of Units for—				Total Units
		Policy 1	Policy 2	Policy 3	Policy 4	
31	portable air compressor	5	5	5	5	20
48	tractor (wheeled)	2	3	1	1	7
51	trailer-mounted generators (10 to 600 kw)	6	7	5	5	23
57	sweeper (street)	1	1	1	1	4
65	railway locomotive	1	1	0	0	2
82	truck-mounted crane cruiser	1	1	1	1	4
91	bus (37 passenger)	4	4	4	6	18
92	sedan	3	6	5	5	19
93	carry-all or station wagon	5	3	3	2	13
94	light truck (1/4 through 1 ton)	54	55	54	54	217
95	medium truck (1-1/2 through 2-1/2 tons)	6	7	5	6	24
96	heavy truck (over 2-1/2 tons)	6	6	6	7	25
	Total	94	99	90	93	376

* Interim failure is any nonaccident failure requiring repair which is not incorporated in a scheduled maintenance action.

MEASURES OF EFFECTIVENESS

As stated in the Introduction, the purpose of the testing and analysis conducted during this study was to determine which of the four maintenance policies under examination is the most cost effective. There are numerous ways to measure cost effectiveness, all dependent on conditions which are imposed upon the equipment and their mode of operation. Originally, this study was initiated with the intention of collecting cost data directly attributable to maintenance required. In other words, cost criteria were computed directly from expenditures of labor and materials. It was determined early in the testing that direct cost alone, however, is not a realistic determinant of the relative merits of the policies under study. For this reason, the additional factors of ***reliability***, ***availability***, and ***frequency*** of preventive maintenance were introduced into the measure of effectiveness and were computed for all the vehicle classes and maintenance policies under analysis. To simplify comparison of the four policies, a measure of vehicle quality has been established which combines these three factors and shows what effect the degree of maintenance has on the vehicle operating capability.

In this study, effectiveness of the maintenance policies is defined in terms of the resulting vehicle reliability. Consequently, cost effectiveness is measured in terms of maintenance cost (interim and scheduled) against the resulting increase in vehicle reliability. In addition, the relative ranking of each maintenance policy is determined in terms of ***reliability***, ***maintenance cost***, and ***unavailability***. These are tabulated, and a decision as to the most desirable policy can be made from a comparison of the three factors. Finally, for purposes of readily visible comparison, the three factors have been combined into an arbitrary measure of effectiveness (**E**), which is defined as:

$$E = \frac{\text{(relative unavailability)(relative maintenance cost)}}{\text{relative reliability}}$$

This measure of effectiveness was established as an evaluation measure solely for application in this particular analysis to show the degree of improvement the four policies have in relation to each other and in relation to maintenance policy 1 (scheduled preventive maintenance), which is currently in effect. It should not be generalized to apply in all cases.

Reliability

Reliability is defined as the probability that a vehicle will satisfactorily operate a specified number of miles or a specified time without a stoppage. Estimates of reliability were obtained through application of the Weibull distribution, which has the following characteristics:

Probability density function is

$$f(x) = \frac{B t^{B-1}}{\eta^B} \exp\left[-(t/\eta)^B\right]$$

where η represents the characteristic life.

The cumulative distribution function is

$$F(x) = 1 - \exp\left[-(t/\eta)^B\right]$$

The reliability function may be expressed in terms of either time or miles. If time is used

$$R(t) = 1 - F(t) = \exp\left[-(t/\eta)^B\right]$$

where **t** is time to failure. If miles are used

$$R(m) = 1 - F(m) = \exp\left[-(m/\eta)^B\right]$$

where **m** is miles to failure.

The resulting reliability curves were plotted for vehicle classes 91 through 96 as a function of miles, as shown in Figure 1. Equipment in classes 31 through 82 did not have odometers; consequently, their reliability was calculated in terms of time. Results from classes 31 through 82 lacked credibility due to the nature of the equipment (see Table 1) and the difficulty of controlling data input. Therefore, the results obtained in the report are based primarily on test data obtained from vehicle classes 91 through 96.

The reliability curves do not provide, in themselves, a readily apparent means of determining the superior maintenance policy. Due to a difference in the shape of the curve, one policy may be superior at a certain mileage and become the poorest as mileage increases. This problem is overcome by determining the areas under the curves; these areas represent the reliability of the component in that interval. Areas under the curves from **m** = 0 to **m** = 6,000 were calculated by computer, and the results are shown in the Appendix, Table A-1. Relative measures of reliability, as influenced by maintenance policy, are also illustrated in Table A-1. These reliability values were obtained by determining the smallest area under the reliability curve within each vehicle class and dividing each other area (associated with vehicles of the same class) by the smallest reliability. These numerical relative values are interpreted as follows: For vehicle class 91 (buses), vehicles of policy 4 are the

most reliable with a relative ranking of 1.562, vehicles of policy 1 follow with a ranking of 1.098, then come vehicles of policy 2 with a ranking of 1.089, and vehicles of policy 3 are the most unreliable with a rank of 1.0. By adding the areas under the reliability curves and taking a weighted average according to the number of vehicles involved, a relative ranking of maintenance policies as regards reliability, independent of vehicle class, is obtainable. This has been done, and the results are listed in Table 2.

Table 2. Relative Reliabilities for All Vehicle Classes
(Criterion: Miles Traveled)

(Largest value indicates greatest reliability.)

Maintenance Policy	Relative Reliability
1 scheduled preventive maintenance	1.112
2 limited preventive maintenance	1.000
3 breakdown maintenance	1.026
4 manufacturer's prescribed preventive maintenance	1.311

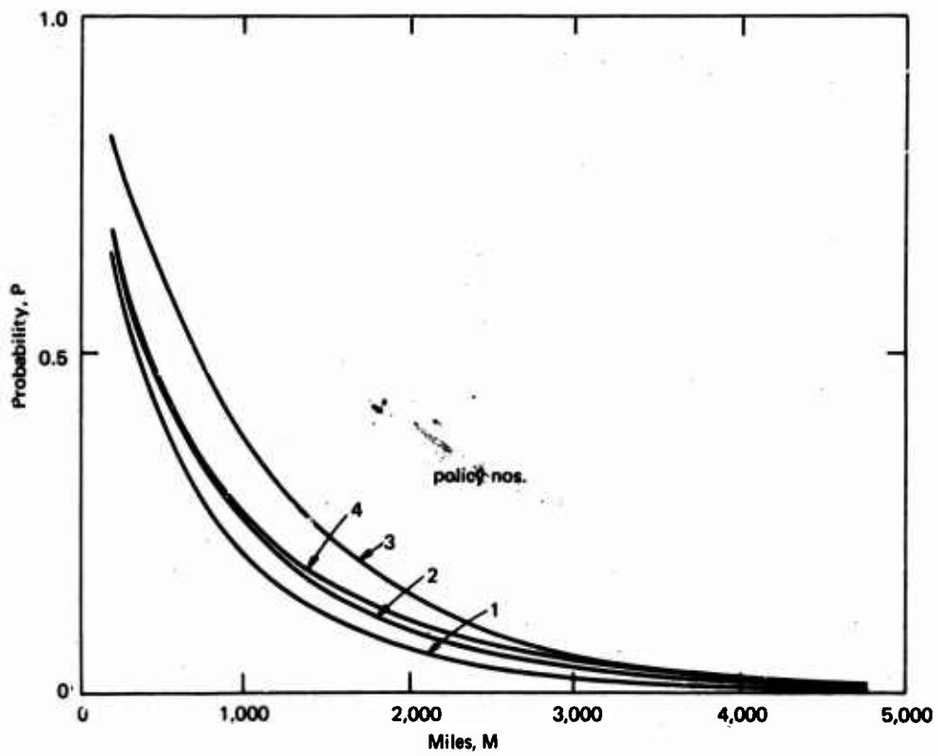

Figure 1. Probability of no interim failure versus miles for vehicle class 95.

Frequency of Preventive Maintenance

The frequency of scheduled maintenance is defined by each preventive maintenance policy. This frequency, however, can be examined in exactly the same manner as the random failures were examined. The results are shown in Table A-2 based on the areas under the scheduled maintenance probability curves. A representative scheduled maintenance curve for vehicle class 95 is shown in Figure 2. Again applying the procedure developed in the previous section, measures of the relative frequency of scheduled maintenance actions as a function of maintenance policy were determined. They are shown in Table 3. Maintenance policy 3 is omitted because it inherently involves no scheduled maintenance.

Table 3. Frequency of Scheduled Maintenance for All Vehicle Classes (Criterion: Miles Traveled)

(Smallest value indicates greatest frequency.)

Maintenance Policy	Relative Frequency of Scheduled Maintenance
1 scheduled preventive maintenance	1.321
2 limited preventive maintenance	1.000
4 manufacturer's prescribed preventive maintenance	1.167

Maintenance Cost

The number of interim failures, the mean repair cost, the maximum deviation of repair cost, and the 90% confidence limits of repair costs, as a function of vehicle class and policy number, are tabulated in Table A-3. Similar data concerning scheduled maintenance are shown in Table A-4. The mean number of interim failures per vehicle, the maximum deviation of failures per vehicle, and the 90% confidence limits are also provided in Table A-5. Similarly, analogous data for scheduled maintenance are shown in Table A-6. Table A-7 provides mileage data (that is, miles traveled by vehicles while on test) for vehicles as a function of vehicle class and preventive maintenance policy. The data in Tables A-3, A-5, and A-7 are sufficient for estimation of the repair costs of interim failures per vehicle per mile. The 90% upper confidence limits for these estimates are shown in Table A-8. The

number of vehicles per policy and the number of events are taken into consideration so that equal weighting is given each vehicle and each failure. Therefore, it is reasonable to compare these numerical cost values as values of merit of the different vehicle classes and maintenance policies as a function of interim failure repair costs. In a similar manner, the data of Tables A-4, A-6, and A-7 provide a means of estimating the cost of scheduled maintenance action per vehicle per mile and are summarized in Table A-9. As with the cost estimates for interim failure repair, these estimates of costs of scheduled maintenance take into account both the number of scheduled maintenance actions and the number of vehicles assigned. Therefore, these are relative indicators of the scheduled maintenance action cost as a function of vehicle class and policy number.

Data of Tables A-8 and A-9 provide a means of determining the least costly maintenance policy for each independent vehicle class with regard to scheduled maintenance and interim failure repair cost. A relative measure of cost has also been obtained by selecting the smallest cost per vehicle per mile within each vehicle class and dividing this number into each cost per vehicle per mile of each other vehicle in that class. This has been done for both preventive maintenance and interim failure cost. The results are shown in Table A-10.

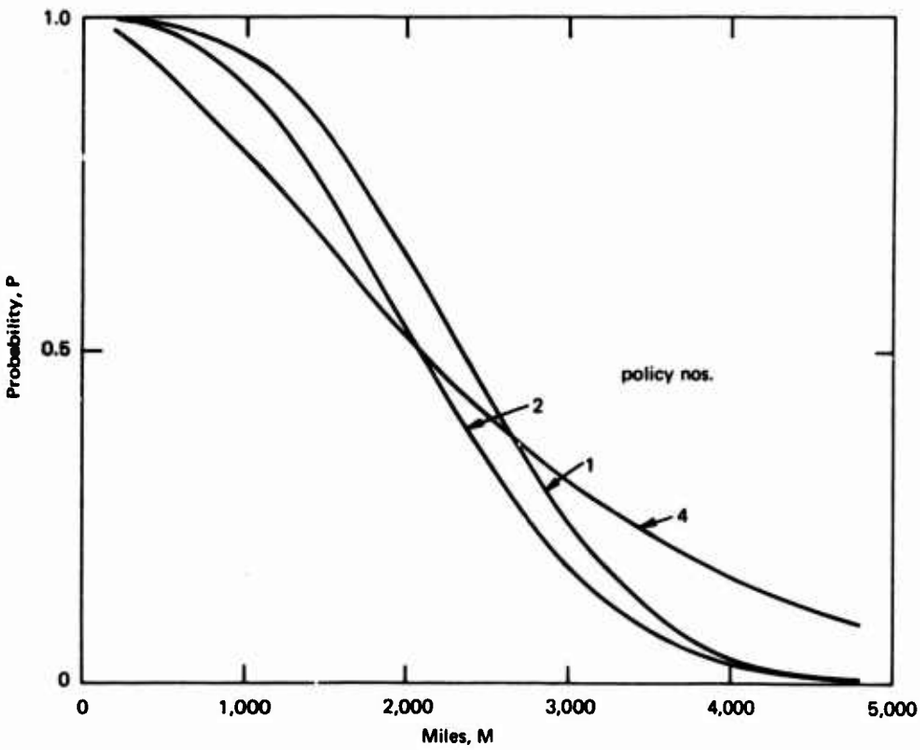

Figure 2. Probability of no scheduled maintenance actions versus miles for vehicle class 95.

Table A-11 shows the total maintenance cost per vehicle per mile as a function of vehicle class and maintenance policy. Relative cost values are obtained as described previously. Through inspection of these relative cost values it is possible to identify, within each vehicle class, the least costly preventive maintenance policy.

Table A-12 shows the sum of maintenance cost per vehicle per mile over all vehicle classes as a function of maintenance policy. Computation of relative cost values revealed that maintenance policy 3 (that is, the breakdown policy) is least costly. However, these data are taken from the shop repair orders for interim repairs only and do not include the cost of putting some vehicles of policy 3 back into operation at the end of the study. Estimates received from the maintenance shop indicate that $1[illegible] will be required to [illegible] vehicles under policy 3 before they can be [illegible] returned to duty. The total maintenance cost under policy 3 based on the mean costs in Table A-3 is $21,819.37. An additional $15,000 would increase the total cost by 68%. To effectively evaluate the four policies, the relative maintenance cost for policy 3 is increased by 68%, and the result is shown in Table A-12. This is considered a more realistic indication of the relative maintenance cost of policy 3, since it takes into account the need to keep vehicles operational.

The adjusted section of Table A-12 shows that for every dollar spent on vehicles of policy 2, $1.87 is spent on vehicles of policy 1, $1.05 spent for policy 4, and $1.39 spent for policy 3. The derivation of these values takes into account the number of vehicles assigned to each maintenance policy, the degree of utility of these vehicles during the test, the number of failures, and the number of scheduled maintenance actions occurring. In other words, these relative values are weighted to account for the differences in sample size; therefore, they are reasonable relative indicators of maintenance cost.

One fact should be mentioned at this point. The purpose of scheduled or preventive maintenance is to reduce interim breakdowns (that is, random failure) and to extend the useful life of the vehicle. The expected life of a vehicle of class 94 (light truck) under preventive maintenance has been found to be about 6 years or 72,000 miles. Class 94 vehicles assigned to policy 3 (the breakdown policy) have traveled an average of 17,700 miles during this test; this is less than 1/4 of the expected life. The data show quite conclusively that vehicles of policy 3 have a greater frequency of interim failures as test time increases and that the cost per repair of interim failure increases with time. Even though the degree to which this will occur is not known, the trend is clearly evident from the data obtained thus far.

Availability

Confidence interval estimates of time loss per vehicle for repair of interim failures and time loss per vehicle for performance of scheduled maintenance, along with the supporting data from which these confidence intervals were computed, are shown in Table A-13. Similarly, confidence interval estimates of labor time per vehicle for repair of interim failures and labor time per vehicle for scheduled maintenance are shown in Table A-14. Table A-15 illustrates the approximate total time loss per vehicle due to maintenance actions (both interim and scheduled maintenance). Table A-16 shows the approximate total labor hours per vehicle required for maintenance.

A relative measure of the influence of maintenance policy upon labor time is obtainable by identifying the smallest upper confidence limit estimate of labor time within each vehicle class and dividing this number into each upper confidence limit estimate for vehicles within that class. When the same procedure is followed to obtain a relative indicator of the influence of maintenance policy upon shop time, the results show that for every hour of labor time per vehicle on policy 4, vehicles of policy 3 require 2.065 hours labor, those of policy 2 require 1.702 hours labor, and those of policy 1 require 1.469 hours labor. Shop time in reality represents vehicle unavailability as a function of either scheduled maintenance or interim maintenance and maintenance policy number.

The data in Table A-11 are summed to arrive at comparative unavailability values for the four maintenance policies. The results are shown in Table 4.

Table 4. Relative Unavailability, Based on Maximum Up-Time Requirement

(Largest value indicates greatest unavailability.)

Maintenance Policy	Relative Unavailability
1 scheduled preventive maintenance	2.37
2 limited preventive maintenance	1.00
3 breakdown maintenance	1.55
4 manufacturer's prescribed preventive maintenance	1.02

These data show that for every hour of unavailability of a vehicle of maintenance policy 2, a vehicle on maintenance policy 3 is unavailable 1.55 hours, a vehicle on policy 1 is unavailable 2.37 hours, and a vehicle on policy 4 is unavailable 1.02 hours. These estimates are realistic relative measures because each vehicle and each repair is weighted equally.

Availability as considered here is estimated under the assumption that vehicles are required constantly. If this is not the case and vehicles are required only during a part of each day, scheduled maintenance actions could be performed when the vehicle is not needed. Repair of interim failures (breakdowns), on the other hand, must be accomplished when they occur, and they cannot occur unless the vehicle is in operation. For this reason, relative unavailabilities, computed the same as discussed above with the exception that shop time for scheduled maintenance is omitted, are again estimated. These estimates of relative unavailability as a function of maintenance policy are shown in Table 5.

Table 5. Relative Unavailability, Based on a Limited Up-Time Requirement

(Largest value indicates greatest unavailability.)

Maintenance Policy		Relative Unavailability
1	scheduled preventive maintenance	1.000
2	limited preventive maintenance	1.148
3	breakdown maintenance	2.649
4	manufacturer's prescribed preventive maintenance	1.293

The relative unavailabilities shown here do not include an estimate of time which will be required to make some vehicles of policy 3 operational again. This could be predicted accurately only if the program were to continue and time for repair were recorded.

RESULTS

Four maintenance policies were analyzed during the course of this study to compare cost effectiveness. Relative measures of reliability, maintenance cost, and availability have been developed and presented individually. These are summarized in Table 6.

Table 6. Summary of Measures of Reliability, Maintenance Cost, and Unavailability

Maintenance Policy	Relative Reliability[a]	Relative Maintenance Cost[b]	Relative Unavailability	
			Assuming Maximum Up-Time Requirement[b]	Assuming Less Than Maximum Up-Time Requirement[b]
	Col (1)	Col (2)	Col (3)	Col (4)
1 scheduled preventive maintenance	1.112	1.870	2.370	1.000
2 limited preventive maintenance	1.000	1.000	1.000	1.148
3 breakdown maintenance	1.026	1.390	1.550	2.649
4 manufacturer's prescribed preventive maintenance	1.311	1.050	1.020	1.293

[a] Smallest value indicates least desirable ranking.
[b] Smallest value indicates most desirable ranking.

Two measures of unavailability have been developed to demonstrate the influence that vehicle use has on the comparison of effectiveness. Column 3 of the table, which assumes that vehicles are required on a 24-hour basis, includes scheduled maintenance as a detriment to vehicle availability. Column 4 does not include scheduled maintenance, and unavailability is based solely on unexpected maintenance (interim failures), since it is assumed that scheduled maintenance could be programed at times when vehicle down-time would not interfere with transportation needs.

In general, the study results show that maintenance policy 4, which is the manufacturer's suggested policy, is the most cost effective. The data in Table 6 show that policy 4 provides the highest degree of reliability at a meager maintenance expense, and with little down-time required. In other words, it is the one policy of the four which does not have a serious drawback that detracts from its overall effectiveness. Maintenance policy 1, on the other hand, has an extremely high preventive maintenance cost as its primary drawback. Policies 2 and 3 result in lower vehicle reliabilities. In addition, policy 3 (the breakdown policy) possesses a high degree of relative unavailability. This unavailability would tend to grow rapidly, and the reliability would decrease if tests were to continue, since the results are based on equipment

which was operated for only 1/4 of its total life cycle. Vehicles under maintenance policy 3 had an accelerating rate of breakdowns as accumulated mileage increased.

Whatever the utility of a vehicle, it is desirable to have a maintenance policy which yields maximum reliability and availability at minimum cost. If all three factors are considered to be of equal weight for comparison purposes, the following relationship can be used to compare the relative effectiveness (E) of the four maintenance policies:

$$E = \frac{\text{(relative unavailability)(relative maintenance cost)}}{\text{relative reliability}}$$

This relationship is an arbitrary, dimensionless value of merit. It is merely a means of combining the three effectiveness factors (reliability, maintenance cost, and unavailability) into one value of merit to provide a relative ranking of the four maintenance policies. Applying this relationship to the data (assuming maximum up-time requirement) yields the values shown in Table 7.

Table 7. Relative Effectiveness (E) of Four Maintenance Policies, Based on Maximum Use

(Smallest E value represents most effective policy.)

Maintenance Policy		E Value
1	scheduled preventive maintenance	3.985
2	limited preventive maintenance	1.000
3	breakdown maintenance	2.099
4	manufacturer's prescribed preventive maintenance	0.816

If it is assumed that vehicles are required at less than maximum up-time, the effectiveness factors are as noted in Table 8.

Comparison of Tables 7 and 8 brings out one interesting feature of the breakdown policy versus preventive maintenance policy. Table 8, based on the assumption that repair time can be scheduled as needed without hindering operations, shows that a "breakdown" policy is extremely undesirable. In Table 7, which assumes that vehicles are required constantly (such as in combat operations), the breakdown policy becomes more desirable than a

high degree of preventive maintenance. In either case, however, both policies are not as desirable as a limited amount of preventive maintenance, such as that prescribed by the manufacturer's recommended policy.

Table 8. Relative Effectiveness (E) of Four Maintenance Policies, Based on Limited Use

(Smallest E value represents most effective policy.)

Maintenance Policy		E Value
1	scheduled preventive maintenance	1.681
2	limited preventive maintenance	1.148
3	breakdown maintenance	3.588
4	manufacturer's prescribed preventive maintenance	1.035

Whatever the means of comparison, the results of this study prove that for the equipment analyzed in this study, it is not desirable to adopt a maintenance policy which goes to extremes with regard to preventive maintenance. Too much preventive maintenance results in a high relative maintenance cost, while a policy of no preventive maintenance results in low reliability and a high unavailability factor. The optimum approach provides a moderate degree of maintenance, as exemplified by policy 4, the manufacturer's recommended policy.

Table A-17 lists the total number of vehicles currently in use by the Navy in each of the vehicle classes (91 through 96) analyzed in this study. In addition, the repair costs for each vehicle experienced during the 3-year duration of this study are recorded. Comparison of the total 3-year repair costs of maintenance policies 1 and 4 yields the results shown in Table 9.

Table 9 shows a difference of $17.7 million in maintenance costs between policies 1 and 4 for a three-year period. A change from preventive maintenance (policy 1) currently in effect at Naval facilities to manufacturer's prescribed maintenance (policy 4) would result in savings of $5.9 million per year on vehicle classes 91 through 96, alone. Even greater savings could result from review of policies on equipment in other vehicle classes if this resulted in reducing the amount of preventive maintenance performed on them.

Table 9. Vehicle Fleet Maintenance Cost for a 3-Year Period Under Maintenance Policies 1 and 4

Vehicle		Vehicle Fleet Maintenance Cost, Policy 1 ($ Million)	Vehicle Fleet Maintenance Cost, Policy 4 ($ Million)
Class	Description		
91	bus	18.3	9.0
92	sedan	4.5	5.4
93	carry-all or station wagon	3.0	4.1
94	light truck (1/4 to 1 ton)	427.5	434.9
95	medium truck (1-1/2 to 2-1/2 tons)	5.9	4.2
96	heavy truck (over 2-1/2 tons)	39.2	23.1
Total		498.40	480.70

FINDINGS

1. Regardless of the equipment availability requirements, policy 4 (manufacturer's prescribed preventive maintenance) results in the highest relative reliability with the smallest downtime and maintenance cost and has been found to be the most cost effective.

2. In spite of the fact that policy 1 (scheduled preventive maintenance) requires the greatest expenditures for maintenance of the four policies compared, it does not produce the greatest equipment reliability.

3. Policy 2 (limited preventive maintenance) has the lowest maintenance cost, but it also results in the lowest vehicle reliability.

4. Policy 3 (breakdown maintenance service) is not a satisfactory policy because of attendant low reliability and availability and the high cost of ultimately restoring inoperable equipment to service.

RECOMMENDATIONS

Based on the results of this study, it is recommended that:

1. Policy 3 (breakdown maintenance) not be adopted for Navy vehicular equipment because of ultimately high costs and low reliability.

2. The preventive maintenance policies currently in effect (described in NAVDOCKS P-300 Management of Transportation Equipment) be revised to require that manufacturer's recommended or prescribed maintenance procedures be followed.

3. A survey of all NAVFAC vehicle repair facilities be conducted to analyze repair data and determine effectiveness of their maintenance policies.

4. Recommendations be made on improving maintenance procedures and facilities to reduce operating costs.

Appendix

TABULATED RESULTS OF NAVY TRANSPORTATION EQUIPMENT STUDY

Table A-1. Relative Vehicle Reliability as a Function of Preventive Maintenance Policy and Vehicle Class (Criterion: Miles Traveled)

Vehicle		Maintenance Policy[a]	Areas Under the Curve[b]	Relative Reliability[c]
Class	Description			
91	bus	1	1,094.6	1.098
		2	1,086.2	1.089
		3	997.5	1.000
		4	1,556.9	1.562
92	sedan	1	2,040.8	1.919
		2	1,063.7	1.000
		3	2,004.3	1.884
		4	2,509.0	2.359
93	carry-all or station wagon	1	1,512.2	1.000
		2	1,601.2	1.059
		3	1,526.3	1.009
		4	2,043.8	1.352
94	light truck (1/4 to 1 ton)	1	1,049.8	1.136
		2	980.8	1.062
		3	923.7	1.000
		4	1,197.8	1.297
95	medium truck (1-1/2 to 2-1/2 tons)	1	626.4	1.000
		2	749.5	1.197
		3	1,022.1	1.632
		4	787.5	1.257
96	heavy truck (over 2-1/2 tons)	1	591.1	2.332
		2	334.5	1.319
		3	253.5	1.000
		4	602.5	2.377

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

[b] Represents probability of vehicle failure versus miles: from $m = 0$ to $m = 6,000$

[c] Largest value indicates greatest reliability

Table A-2. Relative Frequency of Scheduled Maintenance Actions as a Function of Maintenance Policy and Vehicle Class (Criterion: Miles Traveled)

Vehicle		Maintenance Policy[a]	Areas Under the Curve[b]	Relative Frequency of Scheduled Maintenance[c]
Class	Description			
91	bus	1	3,205.1	1.444
		2	2,984.5	1.344
		4	2,219.8	1.000
92	sedan	1	3,499.5	1.329
		2	2,632.3	1.000
		4	4,933.6	1.874
93	carry-all or station wagon	1	3,134.2	1.000
		2	3,443.8	1.099
		4	4,611.9	1.471
94	light truck (1/4 to 1 ton)	1	3,442.9	1.454
		2	2,368.6	1.000
		4	2,880.8	1.216
95	medium truck (1-1/2 to 2-1/2 tons)	1	2,359.8	1.109
		2	2,128.7	1.000
		4	2,356.6	1.107
96	heavy truck (over 2-1/2 tons)	1	2,880.8	1.203
		2	2,991.2	1.249
		4	2,394.4	1.000

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

[b] Represents probability of no scheduled maintenance action versus miles: from m = 0 to m = 6,000

[c] Smallest value indicates greatest frequency.

Table A-3. 90% Confidence Limits of Interim Repair Cost Per Failure

Vehicle		Maintenance Policy[a]	Number of Interim Failures	Mean Cost to Repair Per Failure ($)	Maximum Deviation of Repair Cost Per Failure ($)	90% Confidence Limits of Interim Repair Cost Per Failure ($)	
Class	Description					Upper	Lower
91	bus	1	146	59.76	53.71	67.07	52.45
		2	141	33.69	67.73	43.07	24.31
		3	174	31.97	69.41	40.63	23.31
		4	128	32.55	73.92	43.30	21.80
92	sedan	1	27	13.66	16.05	18.74	8.58
		2	49	14.99	19.81	19.65	10.33
		3	57	20.47	27.73	26.21	14.43
		4	42	20.69	27.94	27.78	13.60
93	carry-all or station wagon	1	39	10.44	13.80	14.08	6.80
		2	37	17.21	21.24	22.95	11.47
		3	56	25.26	44.73	35.09	15.43
		4	35	28.66	91.11	54.00	3.33
94	light truck (1/4 to 1 ton)	1	701	13.32	26.44	14.96	11.68
		2	769	12.85	21.85	14.15	11.55
		3	755	14.44	32.29	16.37	12.51
		4	749	13.70	26.59	15.30	12.10
95	medium truck (1-1/2 to 2-1/2 tons)	1	43	13.83	26.20	20.40	7.26
		2	34	5.27	5.35	6.78	3.76
		3	28	7.26	10.92	10.65	3.87
		4	38	11.61	25.77	18.49	4.73
96	heavy truck (over 2-1/2 tons)	1	129	23.18	69.99	33.32	13.04
		2	204	17.63	52.38	23.66	11.60
		3	182	14.12	39.05	18.88	9.36
		4	151	17.18	53.53	24.35	10.01

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-4. 90% Confidence Limits of Scheduled Maintenance Action Cost Per Event

Vehicle		Maintenance Policy[a]	Number of Scheduled Maintenance Actions	Mean Cost to Repair Per Action ($)	Maximum Deviation of Repair Cost Per Action ($)	90% Confidence Limits of Maintenance Cost Per Repair ($)	
Class	Description					Upper	Lower
91	bus	1	61	44.06	16.58	47.55	40.57
		2	57	22.04	61.65	35.47	8.61
		4	69	21.02	33.85	27.72	14.32
92	sedan	1	27	24.66	36.09	36.09	13.23
		2	37	6.24	5.93	7.84	4.64
		4	24	16.18	16.11	21.59	10.77
93	carry-all or station wagon	1	28	20.81	25.35	28.69	12.93
		2	30	6.43	8.54	8.99	3.87
		4	17	20.99	23.97	30.55	11.43
94	light truck (1/4 to 1 ton)	1	297	20.90	19.98	22.81	18.99
		2	313	11.15	26.09	13.58	8.72
		4	273	20.34	25.29	22.86	17.82
95	medium truck (1-1/2 to 2-1/2 tons)	1	10	25.09	18.74	34.84	15.34
		2	13	6.70	6.22	9.54	3.86
		4	15	10.92	7.69	14.19	7.65
96	heavy truck (over 2-1/2 tons)	1	31	73.99	172.10	124.84	23.14
		2	28	14.34	11.79	18.01	10.67
		4	23	22.77	20.91	29.94	15.60

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-5. 90% Confidence Limits of the Number of Interim Failures Per Vehicle

Vehicle		Maintenance Policy[a]	Mean Number of Interim Failures Per Vehicle	Maximum Deviation of Number of Interim Failures Per Vehicle	90% Confidence Limits of the Number of Interim Failures Per Vehicle	
Class	Description				Lower	Upper
91	bus	1	36.500	11.733	26.85	46.15
		2	35.250	9.287	27.61	44.14
		3	43.500	7.724	37.15	49.85
		4	21.333	14.009	11.92	30.74
92	sedan	1	9.000	6.082	3.22	14.78
		2	8.166	6.524	3.78	12.55
		3	11.400	8.414	5.21	17.59
		4	10.500	6.806	4.90	16.10
93	carry-all or station wagon	1	7.800	6.140	3.28	12.32
		2	12.333	10.263	2.59	22.08
		3	18.666	15.502	3.94	33.39
		4	17.500	7.778	8.45	26.55
94	light truck (1/4 to 1 ton)	1	12.745	10.667	10.38	15.11
		2	13.155	12.176	10.52	15.88
		3	13.981	12.358	11.21	16.75
		4	13.375	10.937	10.97	15.78
95	medium truck (1-1/2 to 2-1/2 tons)	1	7.166	7.678	2.01	12.32
		2	4.857	5.459	1.46	8.25
		3	5.600	4.219	2.50	8.70
		4	7.600	5.813	3.32	11.88
96	heavy truck (over 2-1/2 tons)	1	18.428	18.274	7.07	29.79
		2	15.571	17.135	4.92	26.22
		3	26.000	29.393	7.72	44.28
		4	19.714	16.987	9.15	30.28

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-6. 90% Confidence Limits of the Number of Scheduled Maintenance Actions Per Vehicle

Vehicle		Maintenance Policy[a]	Mean Number of Scheduled Maintenance Actions Per Vehicle	Maximum Deviation of the Number of Scheduled Maintenance Actions Per Vehicle	90% Confidence Limits of the Number of Scheduled Maintenance Actions Per Vehicle	
Class	Description				Lower	Upper
91	bus	1	15.250	5.909	10.39	20.11
		2	14.250	5.439	9.78	18.72
		4	11.500	8.408	5.85	17.15
92	sedan	1	9.000	8.660	0.83	17.17
		2	6.166	3.816	3.60	8.73
		4	6.000	5.597	1.40	10.60
93	carry-all or station wagon	1	5.600	4.505	2.29	8.91
		2	10.000	12.489	1.61	18.39
		4	8.500	0.707	7.68	9.32
94	light truck (1/4 to 1 ton)	1	5.400	4.428	4.42	6.38
		2	5.948	7.027	4.43	7.47
		4	4.875	2.991	4.22	5.53
95	medium truck (1-1/2 to 2-1/2 tons)	1	1.666	2.250	0.15	3.18
		2	1.857	1.676	0.81	2.90
		4	3.000	3.162	0.67	5.33
96	heavy truck (over 2-1/2 tons)	1	4.428	3.408	2.31	6.55
		2	4.000	3.316	1.94	6.06
		4	3.000	2.309	1.56	4.44

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-7. 90% Confidence Limits for Miles Per Vehicle

Vehicle		Maintenance Policy[a]	Number of Vehicles Assigned	Mean Mileage Per Vehicle	Maximum Deviation of Mileage Per Vehicle	90% Confidence Limits of Mileage Per Vehicle	
Class	Description					Upper	Lower
91	bus	1	4	44,637	15,192	57,132	32,142
		2	4	39,954	19,379	55,893	24,015
		3	4	48,533	19,691	67,234	29,832
		4	6	36,229	23,928	52,298	20,160
92	sedan	1	3	27,466	25,257	51,454	3,478
		2	6	16,861	9,166	23,017	10,705
		3	5	35,934	27,085	55,860	16,008
		4	4	38,599	29,032	62,478	14,720
93	carry-all or station wagon	1	5	17,903	19,141	31,984	3,822
		2	3	34,073	34,014	66,377	1,769
		3	3	38,369	29,877	66,744	9,994
		4	2	49,078	1,242	50,523	47,633
94	light truck (1/4 to 1 ton)	1	55	15,108	12,396	17,858	12,358
		2	58	15,171	10,744	17,492	12,850
		3	54	14,246	9,450	16,361	12,131
		4	56	17,369	12,682	20,157	14,581
95	medium truck (1-1/2 to 2-1/2 tons)	1	6	5,929	6,228	10,112	1,746
		2	7	4,881	3,393	6,991	2,771
		3	5	6,328	2,967	8,511	4,145
		4	5	11,276	9,679	18,397	4,155
96	heavy truck (over 2-1/2 tons)	1	7	13,559	9,840	19,677	7,441
		2	7	13,403	10,150	19,714	7,092
		3	7	19,336	32,513	39,551	12,298
		4	7	15,278	9,978	21,482	9,074

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-8. Interim Failure Repair Cost

Vehicle		Maintenance Policy[a]	Upper 90% Confidence Limits		Mean Mileage Per Vehicle	Repair Cost Per Vehicle Per Mile at Approximately 90% Confidence Level ($)
Class	Description		Cost to Repair Per Failure ($)	Number of Interim Failures Per Vehicle		
91	bus	1	67.07	46.15	44,637	0.06934
		2	43.07	44.14	39,954	0.04758
		3	40.63	49.85	48,533	0.04173
		4	43.30	30.74	36,229	0.03674
92	sedan	1	18.74	14.78	27,466	0.01008
		2	19.65	12.55	16,861	0.01463
		3	26.21	17.59	35,934	0.01283
		4	27.78	16.10	38,599	0.01159
93	carry-all or station wagon	1	14.08	12.32	17,903	0.00969
		2	22.95	22.08	34,073	0.01487
		3	35.09	33.39	38,369	0.03054
		4	54.00	26.55	49,078	0.02921
94	light truck (1/4 to 1 ton)	1	14.96	15.11	15,108	0.01496
		2	14.15	15.88	15,171	0.01481
		3	16.37	16.75	14,246	0.01925
		4	15.30	15.78	17,369	0.01390
95	medium truck (1-1/2 to 2-1/2 tons)	1	20.40	12.32	5,929	0.04239
		2	6.78	8.25	4,881	0.01146
		3	10.65	8.70	6,328	0.01464
		4	18.49	11.88	11,276	0.01948
96	heavy truck (over 2-1/2 tons)	1	33.32	29.79	13,559	0.07321
		2	23.66	26.22	13,403	0.04629
		3	18.88	44.28	19,336	0.04324
		4	24.35	30.28	15,278	0.04826

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-9. Scheduled Maintenance Action Cost

Vehicle		Maintenance Policy[a]	Upper 90% Confidence Limits		Mean Mileage Per Vehicle	Scheduled Maintenance Cost Per Vehicle Per Mile at Approximately 90% Confidence Level ($)
Class	Description		Cost Per Scheduled Maintenance Action ($)	Number of Scheduled Maintenance Actions Per Vehicle		
91	bus	1	47.55	20.11	44,637	0.02142
		2	35.47	18.72	39,954	0.01662
		4	27.72	17.15	36,229	0.01312
92	sedan	1	37.90	17.17	27,466	0.02369
		2	7.84	8.73	16,861	0.00406
		4	21.59	10.60	38,599	0.00593
93	carry-all or station wagon	1	28.69	8.91	17,903	0.01428
		2	8.99	18.39	34,073	0.00485
		4	30.55	9.32	49,078	0.00580
94	light truck (1/4 to 1 ton)	1	22.81	6.38	15,108	0.00963
		2	13.58	7.47	15,171	0.00669
		4	22.86	5.53	17,369	0.00728
95	medium truck (1-1/2 to 2-1/2 tons)	1	34.84	3.18	5,929	0.01869
		2	9.54	2.90	4,881	0.00567
		4	14.19	5.33	11,276	0.00671
96	heavy truck (over 2-1/2 tons)	1	124.84	6.55	13,559	0.06030
		2	18.01	6.06	13,403	0.00814
		4	29.94	4.44	15,278	0.00870

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-10. Relative Scheduled and Interim Maintenance Cost as a Function of Maintenance Policy for Each Vehicle Class

(Computed using 90% upper confidence limits of cost per vehicle.)

Vehicle		Maintenance Policy[a]	Relative Scheduled Maintenance Cost Per Vehicle Per Mile[b]	Relative Interim Failure Repair Cost Per Vehicle Per Mile[b]
Class	Description			
91	bus	1	1.6326	1.8873
		2	1.2667	1.2950
		3	–	1.1358
		4	1.0000	1.0000
92	sedan	1	5.8350	1.0000
		2	1.0000	1.4514
		3	–	1.2728
		4	1.4606	1.1498
93	carry-all or station wagon	1	2.9443	1.0000
		2	1.0000	1.5346
		3	–	3.1517
		4	1.1959	3.0144
94	light truck (1/4 to 1 ton)	1	1.4395	1.0763
		2	1.0000	1.0655
		3	–	1.3849
		4	1.0882	1.0000
95	medium truck (1-1/2 to 2-1/2 tons)	1	3.2963	3.6990
		2	1.0000	1.0000
		3	–	1.2775
		4	1.1834	1.6998
96	heavy truck (over 2-1/2 tons)	1	7.4079	1.6931
		2	1.0000	1.0705
		3	–	1.0000
		4	1.0688	1.1161

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

[b] Smallest value indicates least cost

Table A-11. Relative Maintenance Cost (Both Preventive and Interim) as a Function of Maintenance Policy for Each Independent Vehicle Class

(Computed using 90% upper confidence limits of cost per vehicle.)

Vehicle		Maintenance Policy[a]	Maintenance Cost Per Vehicle Per Mile ($)	Relative Maintenance Cost Per Vehicle Per Mile[b]
Class	Description			
91	bus	1	0.09076	2.1749
		2	0.06420	1.5385
		3	0.04173	1.0000
		4	0.04986	1.9482
92	sedan	1	0.03377	2.6321
		2	0.01869	1.4567
		3	0.01283	1.0000
		4	0.01752	1.3655
93	carry-all or station wagon	1	0.02397	1.2155
		2	0.01972	1.0000
		3	0.03054	1.5487
		4	0.03501	1.7754
94	light truck (1/4 to 1 ton)	1	0.02459	1.2774
		2	0.02150	1.1169
		3	0.01925	1.0000
		4	0.02118	1.1003
95	medium truck (1-1/2 to 2-1/2 tons)	1	0.06108	4.1721
		2	0.01713	1.1701
		3	0.01464	1.0000
		4	0.02619	1.7889
96	heavy truck (over 2-1/2 tons)	1	0.13351	3.0877
		2	0.05443	1.2588
		3	0.04324	1.0000
		4	0.05696	1.3173

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

[b] Smallest value indicates least cost

Table A-12. Relative Cost for Both Scheduled and Interim Maintenance as a Function of Maintenance Policy (All Vehicle Classes)

Maintenance Policy[a]	Maintenance Cost Per Vehicle Per Mile ($)	Relative Maintenance Cost Per Vehicle Per Mile[b]
Basic Maintenance Cost Data		
1	0.36768	2.2664
2	0.19567	1.2061
3	0.16223	1.0000
4	0.20672	1.2742
Adjusted Maintenance Cost Data[c]		
1	0.36768	1.8790
2	0.19567	1.0000
3	0.27254	1.3928
4	0.20672	1.0564

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

[b] Smallest value indicates lowest cost

[c] Basic cost data for policy 3 increased by 68% to cover cost ($15,000) of repairing inoperable vehicles at end of study

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Table A-13. Confidence Interval Estimates of Time Loss Per Vehicle Due to Repair c
Failures and Time Loss Per Vehicle Due to Scheduled Maintenance

Vehicle		Maintenance Policy[a]	Repairs Per Vehicle		Shop Time Per Repair (hr)		Mean Shop Per Veh (hr)
Class	Description		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)	
			Interim				
91	bus	1	36.500	11.733	46.0	100.6	1,679
		2	35.250	9.287	58.4	139.6	2,058
		3	43.500	7.724	62.7	178.6	2,727
		4	21.333	14.009	73.0	402.9	1,557
92	sedan	1	9.000	6.082	18.3	30.0	164
		2	8.166	6.524	26.7	49.7	218
		3	11.400	8.414	32.5	54.3	370
		4	10.500	6.806	11.1	24.0	116
93	carry-all or station wagon	1	7.800	6.140	17.7	54.7	138
		2	12.333	10.263	31.8	77.4	392
		3	18.666	15.502	53.1	137.2	991
		4	17.500	7.778	37.9	147.0	663
94	light truck (1/4 to 1 ton)	1	12.745	10.667	19.2	61.8	244
		2	13.155	12.176	23.2	68.6	302
		3	13.981	12.358	34.6	120.5	483
		4	13.375	10.937	25.6	148.5	342
95	medium truck (1-1/2 to 2-1/2 tons)	1	7.166	7.678	33.4	63.9	239
		2	4.857	5.459	28.6	80.5	138
		3	5.600	4.219	38.3	91.7	214
		4	7.600	5.813	18.2	40.1	138
96	heavy truck (over 2-1/2 tons)	1	18.428	18.274	46.6	94.0	858
		2	15.571	17.135	38.1	86.5	593
		3	26.000	29.393	97.1	846.1	2,524
		4	19.714	16.987	27.5	81.6	542
			Scheduled				
91	bus	1	15.250	5.909	118.8	238.1	1,811
		2	14.250	5.439	49.7	123.1	708
		4	11.500	8.408	33.2	62.3	381
92	sedan	1	9.000	8.660	385.8	1,676.1	3,472
		2	6.166	3.816	16.7	31.9	103
		4	6.000	5.597	28.2	63.9	169
93	carry-all or station wagon	1	5.600	4.505	46.4	41.6	25
		2	10.000	12.489	25.1	41.6	25
		4	8.500	0.707	37.9	65.4	32

Table A-13. Confidence Interval Estimates of Time Loss Per Vehicle Due to Repair of I
Failures and Time Loss Per Vehicle Due to Scheduled Maintenance

Vehicle		Maintenance Policy[a]	Repairs Per Vehicle		Shop Time Per Repair (hr)		Mean Shop Ti Per Vehicle (hr)
Class	Description		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)	
Interim							
91	bus	1	36.500	11.733	46.0	100.6	1,679.0
		2	35.250	9.287	58.4	139.6	2,058.6
		3	43.500	7.724	62.7	178.6	2,727.5
		4	21.333	14.009	73.0	402.9	1,557.3
92	sedan	1	9.000	6.082	18.3	30.0	164.7
		2	8.166	6.524	26.7	49.7	218.0
		3	11.400	8.414	32.5	54.3	370.5
		4	10.500	6.806	11.1	24.0	116.6
93	carry-all or station wagon	1	7.800	6.140	17.7	54.7	138.1
		2	12.333	10.263	31.8	77.4	392.2
		3	18.666	15.502	53.1	137.2	991.2
		4	17.500	7.778	37.9	147.0	663.3
94	light truck (1/4 to 1 ton)	1	12.745	10.667	19.2	61.8	244.7
		2	13.155	12.176	23.2	68.6	302.9
		3	13.981	12.358	34.6	120.5	483.7
		4	13.375	10.937	25.6	148.5	342.4
95	medium truck (1-1/2 to 2-1/2 tons)	1	7.166	7.678	33.4	63.9	239.3
		2	4.857	5.459	28.6	80.5	138.9
		3	5.600	4.219	38.3	91.7	214.5
		4	7.600	5.813	18.2	40.1	138.3
96	heavy truck (over 2-1/2 tons)	1	18.428	18.274	46.6	94.0	858.7
		2	15.571	17.135	38.1	86.5	593.3
		3	26.000	29.393	97.1	846.1	2,524.6
		4	19.714	16.987	27.5	81.6	542.1
Scheduled							
91	bus	1	15.250	5.909	118.8	238.1	1,811.7
		2	14.250	5.439	43.7	123.1	708.2
		4	11.500	8.408	33.2	62.3	381.8
92	sedan	1	9.000	8.660	385.8	1,676.1	3,472.2
		2	6.166	3.816	16.7	31.9	103.0
		4	6.000	5.597	28.2	63.9	169.2
93	carry-all or station wagon	1	5.600	4.505	46.4	41.6	251.0
		2	10.000	12.489	25.1	41.6	251.0
		4	8.500	0.707	37.9	65.4	322.2

Table A-13. Confidence Interval Estimates of Time Loss Per Vehicle Due to Repair of Interim Failures and Time Loss Per Vehicle Due to Scheduled Maintenance

	Maintenance Policy[a]	Repairs Per Vehicle		Shop Time Per Repair (hr)		Mean Shop Time Per Vehicle (hr)	90% Confidence Interval of Shop Time Per Vehicle (hr)	
on		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)		Lower Limit	Upper Limit
				Interim				
	1	36.500	11.733	46.0	100.6	1,679.0	1,105.7	2,252.4
	2	35.250	9.287	58.4	139.6	2,058.6	1,301.8	2,815.5
	3	43.500	7.724	62.7	178.6	2,727.5	1,698.3	3,756.8
	4	21.333	14.009	73.0	402.9	1,557.3	159.7	2,954.9
	1	9.000	6.082	18.3	30.0	164.7	44.0	285.4
	2	8.166	6.524	26.7	49.7	218.0	81.8	354.2
	3	11.400	8.414	32.5	54.3	370.5	176.1	564.9
	4	10.500	6.806	11.1	24.0	116.6	33.5	199.8
l	1	7.800	6.140	17.7	54.7	138.1	0	279.0
n	2	12.333	10.263	31.8	77.4	392.2	46.0	738.4
	3	18.666	15.502	53.1	137.2	991.2	247.7	1,734.7
	4	17.500	7.778	37.9	147.0	663.3	0	1,460.4
	1	12.745	10.667	19.2	61.8	244.7	183.1	306.3
k	2	13.155	12.176	23.2	68.6	302.9	232.7	373.1
on)	3	13.981	12.358	34.6	120.5	483.7	357.2	610.2
	4	13.375	10.937	25.6	148.5	342.4	206.2	478.6
	1	7.166	7.678	33.4	63.9	239.3	60.2	418.4
ıck	2	4.857	5.459	28.6	80.5	138.9	0	293.3
2 tons)	3	5.600	4.219	38.3	91.7	214.5	4.7	424.3
	4	7.600	5.813	18.2	40.1	138.3	28.8	247.8
	1	18.428	18.274	46.6	94.0	858.7	484.4	1,233.0
ck	2	15.571	17.135	38.1	86.5	593.3	278.2	908.4
tons)	3	26.000	29.393	97.1	846.1	2,524.6	0	5,555.3
	4	19.714	16.987	27.5	81.6	542.1	251.4	832.8
				Scheduled				
	1	15.250	5.909	118.8	238.1	1,811.7	899.1	2,794.3
	2	14.250	5.439	49.7	123.1	708.2	267.1	1,149.3
	4	11.500	8.408	33.2	62.3	381.8	184.8	578.8
	1	9.000	8.660	385.8	1,676.1	3,472.2	0	9,302.0
	2	6.166	3.816	16.7	31.9	103.0	32.6	173.4
	4	6.000	5.597	28.2	63.9	169.2	0	351.0
	1	5.600	4.505	46.4	41.6	251.0	32.0	470.0
n	2	10.000	12.489	25.1	41.6	251.0	32.0	470.0
	4	8.500	0.707	37.9	65.4	322.2	89.7	554.7

continued

Table A-13. Continued

Vehicle		Maintenance Policy[a]	Repairs Per Vehicle		Shop Time Per Repair (hr)		Mean Shop Time Per Vehicle (hr)	
Class	Description		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)		Low
94	light truck (1/4 to 1 ton)	1	5.400	4.428	61.4	101.4	331.6	
		2	5.948	7.027	45.8	115.3	272.4	
		4	4.875	–	45.3	93.3	217.4	
95	medium truck (1-1/2 to 2-1/2 tons)	1	1.666	2.250	146.4	195.5	243.9	
		2	1.857	1.676	62.5	65.2	116.1	
		4	3.000	3.162	35.5	42.6	106.5	
96	heavy truck (over 2-1/2 tons)	1	4.428	3.408	150.3	185.2	664.5	
		2	4.000	3.316	47.0	42.7	188.0	
		4	3.000	2.309	40.7	58.2	122.1	

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-13. Continued

	Maintenance Policy[a]	Repairs Per Vehicle		Shop Time Per Repair (hr)		Mean Shop Time Per Vehicle (hr)	90% Confidence Interval of Shop Time Per Vehicle (hr)	
		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)		Lower Limit	Upper Limit
	1	5.400	4.428	61.4	101.4	331.6	253.4	409.8
	2	5.948	7.027	45.8	115.3	272.4	183.2	361.6
	4	4.875	–	45.3	93.3	217.4	158.6	276.2
	1	1.666	2.250	146.4	195.5	243.9	0	584.5
	2	1.857	1.676	62.5	65.2	116.1	13.1	219.1
	4	3.000	3.162	35.5	42.6	106.5	0	220.4
	1	4.428	3.408	150.3	185.2	664.5	271.8	1,059.2
	2	4.000	3.316	47.0	42.7	188.0	86.4	289.6
	4	3.000	2.309	40.7	58.2	122.1	55.5	188.7

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Table A-14. Confidence Interval Estimates of Labor Time Per Vehicle for Repair of Interi
Failure and Labor Time Per Vehicle for Scheduled Maintenance

Vehicle		Maintenance Policy[a]	Repairs Per Vehicle		Labor Time Per Repair (hr)		Mean Labor Time Per Vehicle (hr)
Class	Description		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)	
Interim							
91	bus	1	36.500	11.733	2.2	3.5	80.3
		2	35.250	9.287	2.7	3.8	95.2
		3	43.500	7.724	2.7	4.1	117.5
		4	21.33	14.009	2.3	4.9	49.1
92	sedan	1	9.000	6.082	1.7	1.8	15.3
		2	8.166	6.524	1.9	2.3	15.5
		3	11.400	8.414	2.2	2.8	25.1
		4	10.500	6.806	2.1	3.3	22.1
93	carry-all or station wagon	1	7.800	6.140	1.3	1.3	10.1
		2	12.333	10.263	1.5	1.8	18.5
		3	18.666	15.502	2.4	3.7	44.8
		4	17.500	7.778	2.1	5.7	36.8
94	light truck (1/4 to 1 ton)	1	12.745	10.667	1.1	2.0	14.0
		2	13.155	12.176	1.2	2.1	15.8
		3	13.981	12.358	1.5	2.8	21.0
		4	13.375	10.937	1.2	1.9	16.1
95	medium truck (1-1/2 to 2-1/2 tons)	1	7.166	7.678	2.3	4.2	16.5
		2	4.857	5.459	1.1	1.1	5.3
		3	5.600	4.219	1.4	1.6	7.8
		4	7.600	5.813	1.4	2.3	10.6
96	heavy truck (over 2-1/2 tons)	1	18.428	18.274	2.1	3.4	38.7
		2	15.571	17.135	2.1	3.6	32.7
		3	26.000	29.393	2.2	3.5	57.2
		4	19.714	16.987	2.3	4.0	45.3
Scheduled							
91	bus	1	15.250	5.909	6.1	6.7	93.0
		2	14.250	5.439	2.9	3.9	41.3
		4	11.500	8.408	3.4	4.5	39.1
92	sedan	1	9.000	8.660	4.7	6.0	42.3
		2	6.166	3.816	1.2	1.1	7.4
		4	6.000	5.597	3.1	3.0	18.6
93	carry-all o station wagon	1	5.600	4.505	3.6	2.8	20.2
		2	10.000	12.489	1.3	2.3	13.0
		4	8.500	0.707	4.2	4.9	35.7

A-14. Confidence Interval Estimates of Labor Time Per Vehicle for Repair of Interim Failure and Labor Time Per Vehicle for Scheduled Maintenance

tenance licy[a]	Repairs Per Vehicle		Labor Time Per Repair (hr)		Mean Labor Time Per Vehicle (hr)	90% Confidence Interval of Labor Time Per Vehicle (hr)	
	Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)		Lower Limit	Upper Limit
			Interim				
1	36.500	11.733	2.2	3.5	80.3	59.4	101.2
2	35.250	9.287	2.7	3.8	95.2	73.2	117.3
3	43.500	7.724	2.7	4.1	117.5	92.7	142.3
4	21.33	14.009	2.3	4.9	49.1	29.2	68.9
1	9.000	6.082	1.7	1.8	15.3	6.9	23.7
2	8.166	6.524	1.9	2.3	15.5	8.2	22.8
3	11.400	8.414	2.2	2.8	25.1	14.1	36.1
4	10.500	6.806	2.1	3.3	22.1	9.7	34.5
1	7.800	6.140	1.3	1.3	10.1	5.3	14.9
2	12.333	10.263	1.5	1.8	18.5	8.3	28.7
3	18.666	15.502	2.4	3.7	44.8	21.4	68.2
4	17.500	7.778	2.1	5.7	36.8	4.6	69.0
1	12.745	10.667	1.1	2.0	14.0	11.7	16.3
2	13.155	12.176	1.2	2.1	15.8	13.3	18.3
3	13.981	12.358	1.5	2.8	21.0	17.5	24.5
4	13.375	10.937	1.2	1.9	16.1	13.8	18.4
1	7.166	7.678	2.3	4.2	16.5	4.5	28.5
2	4.857	5.459	1.1	1.1	5.3	2.1	8.5
3	5.600	4.219	1.4	1.6	7.8	3.2	12.4
4	7.600	5.813	1.4	2.3	10.6	3.8	17.4
	18.428	18.274	2.1	3.4	38.7	24.1	53.3
2	15.571	17.135	2.1	3.6	32.7	18.7	47.2
3	26.000	29.393	2.2	3.5	57.2	38.2	76.2
4	19.714	16.987	2.3	4.0	45.3	28.8	61.8
			Scheduled				
	15.250	5.909	6.1	6.7	93.0	63.9	122.1
	14.250	5.439	2.9	3.9	41.3	25.8	56.8
	11.500	8.408	3.4	4.5	39.1	23.2	55.0
	9.000	8.660	4.7	6.0	42.3	12.4	72.2
	6.166	3.816	1.2	1.1	7.4	4.3	10.5
	6.000	5.597	3.1	3.0	18.6	6.8	30.5
	5.600	4.505	3.6	2.8	20.2	10.3	30.1
	10.000	12.489	1.3	2.3	13.0	1.2	24.8
	8.500	0.707	4.2	4.9	35.7	17.9	53.5

continued

Table A-14. Continued

Vehicle		Maintenance Policy[a]	Repairs Per Vehicle		Labor Time Per Repair (hr)		Mean Labor T Per Vehicle (hr)
Class	Description		Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)	
94	light truck (1/4 to 1 ton)	1	5.400	4.428	3.8	3.2	20.5
		2	5.948	7.027	1.8	2.5	10.7
		4	4.875	2.991	3.4	3.8	16.6
95	medium truck (1-1/2 to 2-1/2 tons)	1	1.666	2.250	5.2	3.8	8.7
		2	1.857	1.676	1.2	1.0	2.2
		4	3.000	3.162	2.1	1.7	6.3
96	heavy truck (over 2-1/2 tons)	1	4.428	3.408	7.3	7.7	32.3
		2	4.000	3.316	2.5	1.9	10.0
		4	3.000	2.309	4.1	4.0	12.3

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-14. Continued

aintenance Policy[a]	Repairs Per Vehicle		Labor Time Per Repair (hr)		Mean Labor Time Per Vehicle (hr)	90% Confidence Interval of Labor Time Per Vehicle (hr)	
	Mean Number	Maximum Deviation	Mean Time (hr)	Maximum Deviation (hr)		Lower Limit	Upper Limit
1	5.400	4.428	3.8	3.2	20.5	17.3	23.7
2	5.948	7.027	1.8	2.5	10.7	8.3	13.1
4	4.875	2.991	3.4	3.8	16.6	13.7	19.5
1	1.666	2.250	5.2	3.8	8.7	0	18.1
2	1.857	1.676	1.2	1.0	2.2	0.4	4.0
4	3.000	3.162	2.1	1.7	6.3	1.3	11.3
1	4.428	3.408	7.3	7.7	32.3	14.9	49.7
2	4.000	3.316	2.5	1.9	10.0	5.0	115.0
4	3.000	2.309	4.1	4.0	12.3	4.6	20.0

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Table A-15. Total Time Loss Due to Maintenance Over 4-Year Study Period

Vehicle		Maintenance Policy[a]	Average Time Lost (hr) Per Vehicle for—		Approximate Total Time Loss Per Vehicle (hr)
Class	Description		Scheduled Maintenance	Interim Maintenance	
91	bus	1	1,811.7	1,679.0	3,490.7
		2	708.2	2,058.6	2,766.8
		3	–	2,727.5	2,727.5
		4	381.8	1,557.3	1,939.1
92	sedan	1	3,472.2	164.7	3,636.9
		2	103.0	218.0	321.0
		3	–	370.5	370.5
		4	169.2	116.6	285.8
93	carry-all or station wagon	1	259.8	138.1	397.9
		2	251.0	392.2	643.2
		3	–	991.2	991.2
		4	322.2	663.3	985.5
94	light truck (1/4 to 1 ton)	1	331.6	244.7	576.3
		2	272.4	302.9	575.3
		3	–	483.7	483.7
		4	217.4	342.4	559.8
95	medium truck (1-1/2 to 2-1/2 tons)	1	243.9	239.3	483.2
		2	116.1	138.9	255.0
		3	–	214.5	214.5
		4	106.5	138.3	244.8
96	heavy truck (over 2-1/2 tons)	1	665.5	858.7	1,524.2
		2	188.0	593.3	781.3
		3	–	2,524.6	2,524.6
		4	122.1	542.1	664.2

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-16. Labor Time Required for Maintenance

Vehicle		Maintenance Policy[a]	Average Labor Time (hr) Per Vehicle for—		Approximate Total Labor Time Per Vehicle (hr)
Class	Description		Scheduled Maintenance	Interim Maintenance	
91	bus	1	93.0	80.3	173.3
		2	41.3	95.2	136.5
		3	–	117.5	117.5
		4	39.1	49.1	88.2
92	sedan	1	42.3	15.3	57.6
		2	7.4	15.5	22.9
		3	–	18.6	25.1
		4	18.6	22.1	40.7
93	carry-all or station wagon	1	20.2	10.1	30.3
		2	13.0	18.5	31.5
		3	–	44.0	44.8
		4	35.7	36.8	72.5
94	light truck (1/4 to 1 ton)	1	20.5	14.0	34.5
		2	10.7	15.8	26.5
		3	–	21.0	21.0
		4	16.6	16.1	32.7
95	medium truck (1-1/2 to 2-1/2 tons)	1	8.7	16.5	25.2
		2	2.2	5.3	7.5
		3	–	7.8	77.8
		4	6.3	10.6	16.9
96	heavy truck (over 2-1/2 tons)	1	32.3	38.7	71.0
		2	10.0	32.7	42.7
		3	–	57.2	57.2
		4	12.3	45.3	57.6

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-17. Relative Unavailability as a Function of Vehicle Class and Maintenance Policy

(Computed at 90% confidence levels.)

Vehicle		Maintenance Policy[a]	Relative Unavailability Because of—	
Class	Description		Interim Maintenance	Scheduled Maintenance
91	bus	1	1.000	4.828
		2	1.250	1.986
		3	1.668	–
		4	1.312	1.000
92	sedan	1	1.428	53.64
		2	1.773	1.000
		3	2.827	–
		4	1.000	2.024
93	carry-all or station wagon	1	1.000	1.000
		2	2.647	1.162
		3	6.218	–
		4	5.234	1.372
94	light truck (1/4 to 1 ton)	1	1.000	1.484
		2	1.218	1.309
		3	1.992	–
		4	1.563	1.000
95	medium truck (1-1/2 to 2-1/2 tons)	1	1.688	2.668
		2	1.184	1.000
		3	1.712	–
		4	1.000	1.006
96	heavy truck (over 2-1/2 tons)	1	1.481	5.613
		2	1.091	1.535
		3	6.671	–
		4	1.000	1.000

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

Table A-18. Determination of Cost Savings Realized by Changing From Policy 1 to Pc

Vehicle		Maintenance Policy[a]	Number of Interim Failures	Mean Cost to Repair Per Failure ($)	Total Interim Cost ($)	Number of Scheduled Maintenance Actions	Mean Cost to Repair Per Failure ($)	Total Scheduled Cost ($)
Class	Description							
91	bus	1	146	59.76	8,724.96	61	44.06	2,687.66
		4	128	32.55	4,166.40	69	21.02	1,450.38
92	sedan	1	27	13.66	368.82	27	24.66	665.82
		4	42	20.69	868.98	24	16.18	388.32
93	carry-all or station wagon	1	39	10.44	407.16	28	20.81	582.68
		4	35	28.66	1,003.10	17	20.99	356.83
94	light truck (1/4 to 1 ton)	1	701	13.32	9,337.32	297	20.90	6,207.30
		4	749	13.70	10,261.30	273	20.34	5,552.82
95	medium truck (1-1/2 to 2-1/2 tons)	1	43	13.83	594.69	10	25.09	250.90
		4	38	11.61	441.18	15	10.92	163.80
96	heavy truck (over 2-1/2 tons)	1	129	23.18	2,990.22	31	73.99	2,293.69
		4	151	17.18	2,594.18	23	22.77	523.71

[a] Policy 1—scheduled preventive maintenance
Policy 2—limited preventive maintenance
Policy 3—breakdown maintenance
Policy 4—manufacturer's prescribed preventive maintenance

B

From Policy 1 to Policy 4

ost air e ($)	Total Scheduled Cost ($)	Total Repair Cost ($) Per Vehicle	Number of Vehicles in Navy Use	Total 3-Year Fleet Repair Cost (Million $)
	2,687.66	11,412.62	1,604	18.3
	1,450.38	5,616.78		9.0
	665.82	1,034.64	4,341	4.5
	388.32	1,257.30		5.4
	582.68	989.84	2,995	3.0
	356.83	1,359.93		4.1
	6,207.30	15,544.62	27,504	427.5
	5,552.82	15,814.12		434.9
	250.90	845.59	6,939	5.9
	163.80	604.98		4.2
	2,293.69	5,283.91	7,437	39.2
	523.71	3,117.89	–	23.1
			50,820	